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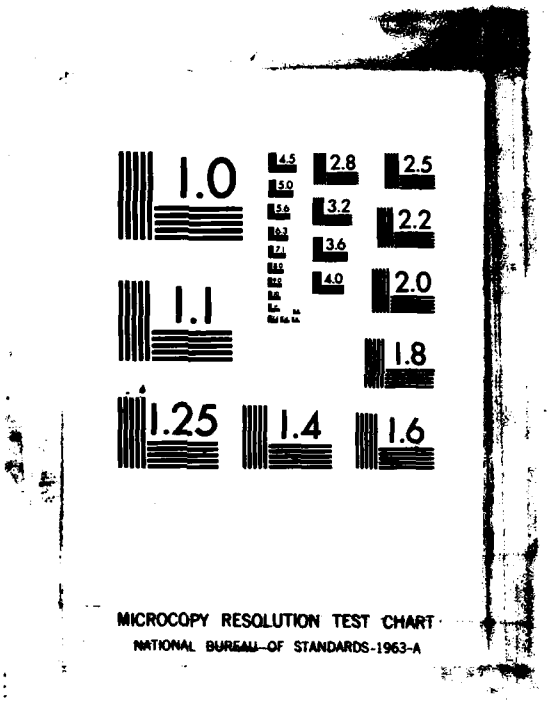
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MULTIVARIATE ANALYSIS AND ITS APPLICATIONS

Progress Report

December 15, 1981-December 31, 1983

Contract F49620-82-K-0001

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A number of topics in multivariate analysis were studied during this period. Technical reports were produced in the following areas —— rejection of multivariate outliers, multivariate gamma distributions and their applications in reliability, testing for positive quadrant dependence in ordinal contingency tables, convexity properties of entropy functions and analysis of diversity, use of diversity and distance measures in the analysis of qualitative data, inference on linear models with fixed effects, limit theorems for the eigenvalues of the sample covariance matrix, concepts of setwise dependence, convexity of bivariate elliptically contoured distributions, admissible linear estimation in singular linear models, standard errors of posterior distributions, and maximum likelihood fitting of STARMAX models to incomplete space-time series data. This report summarizes progress made during this period in these areas.

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The work done during the period of December 15, 1981 to December 31, 1983 under the Contract F49620-82-K-0001 is reported in various technical reports published by the Center for Multivariate Analysis. These reports were already sent to the Air Force Office of Scientific Research/NM. Abstracts of the contents of these reports are given in this report.

Technical Report #82-01 (April, 1982)

Selection of Variables Under Univariate Regression Models

P. R. Krishnaiah

In this paper, the author reviews some methods of selection of variables under univariate regression models. The methods reviewed are forward selection, stepwise regression, backward elimination, overall F test and finite intersection tests (FIT). Some of the drawbacks of the first three methods are also discussed. Also, the author discusses some of the merits of the FIT over the overall F test.

Technical Report #82-02 (April, 1982)

Invariant Confidence Sequences for Some Parameters in a Multivariate Linear Regression Model

B. K. Sinha and S. K. Sarkar

Let $\underset{\sim}{X}_1, \underset{\sim}{X}_2, \ldots$ be independent p-variate normal vectors with $E\,\underset{\sim}{X}_\alpha = \beta\,\underset{\sim}{Y}_\alpha$, $\alpha=1,2,\ldots$ and same p.d. dispersion matrix Σ. Here β: pxq and Σ are unknown parameters and $\underset{\sim}{Y}_\alpha$'s are known qx1 vectors. Writing $\beta = (\beta_1\ \beta_2)' = (\beta_{(1)}\ \beta_{(2)})$ with β_i: $p_i$xq$(p_1+p_2=p)$ and $\beta_{(i)}$: pxq$_i$$(q_1+q_2=q)$, we have constructed invariant confidence sequences for (i) β, (ii) $\beta_{(1)}$, (iii) β_1 when $\beta_2 = 0$ and (iv) $\sigma^2 = |\Sigma|$. This uses the basic ideas of Robbins (1970) and generalizes some of his and Lai's (1976) results. In the process alternative simpler solutions of some of Khan's results (1978) are obtained.

Technical Report #82-06 (April, 1982)

Measures of Diversity and Applications

C. Radhakrishna Rao

Two general methods of obtaining measures of diversity within a population are discussed. One is based on an intrinsic notion of dissimilarity between individuals and the other makes use of the concepts of entropy.

Methods for apportionment of diversity in a hierarchically classified set of populations are discussed. An example is given using genetic data.

The concept of analysis of diversity as a generalization of analysis of variance is developed for populations, classified by combinations of different levels of chosen factors. The method is illustrated with an analysis of sociological data.

Technical Report #82-07 (April, 1982)

Deny's Theorem and Its Applications to Characterizations of Probability Distributions

C. Radhakrishna Rao

A theorem of Deny is stated and its applications to a number of characterization problems of probability distributions are given. During the last fifteen years, a number of characterizations of the exponential, Weibull, stable, Pareto and geometric distributions have been considered by a number of authors. The proofs given in the different cases range from applications of function theory and Laplace transform to real variable techniques and differential equations. A special case of Deny's theorem recently proved by Lau and Rao (1982 a,b) and a certain discrete version of the Lau-Rao formulation proved earlier by Shanbhag (1977) provide a unified approach to all these problems and leads in many cases to stronger results.

Technical Report #82-08 (April, 1982)

On the Selection of Variables Under Regression Models Using Krishnaiah's Finite Intersection Tests

James L. Schmidhammer

The application of Krishnaiah's Finite Intersection Test to the selection of variables in univariate and multivariate statistical regression is examined. The multivariate F distribution is defined, and several probability inequalities useful for the calculation of critical values in the multivariate F distribution are reviewed. The use of the procedure is illustrated on both a univariate and a multivariate set of data.

Technical Report #82-10 (May, 1982)

Asymptotic Distributions of Functions of the Eigenvalues of the Doubly Noncentral Multivariate F Matrix

C. Fang and P. R. Krishnaiah

In this paper, the authors derived asymptotic expressions for joint distributions of certain functions of the eigenvalues of the doubly noncentral multivariate F matrix. These expressions are in terms of the multivariate normal density and multivariate Hermite polynomials. Some applications of the above results are also discussed.

Technical Report #82-11 (May, 1982)

A-1

Inequalities on Distributions: Bivariate and Multivariate

Henry W. Block and Allan R. Sampson

Inequalities concerning bivariate and multivariate distributions in statistics are surveyed, as well as historical background. Subjects treated include inequalities arising through positive and negative dependence; Boole, Bonferroni and Frechet inequalities; convex symmetric set inequalities; stochastic ordering; stochastic majorization and inequalities obtained by majorization; Chebyshev and Kolmogorov-type inequalities; multivariate moment inequalities; and applications to simultaneous inference, unbiased testing and reliability theory.

Technical Report #82-13 (June, 1982)

Third Order Efficiency of MLE - A Counter-example

J. K. Ghosh and B. K. Sinha

We give an example of a curved exponential where the maximum likelihood estimate is not third order efficient either in the sense of Fisher-Rao or Rao.

Technical Report #82-15 (June, 1982)

Selection of Variables in Discriminant Analysis

P. R. Krishnaiah

In this paper, the author gives a review of some techniques for the selection of variables in discriminant analysis.

Technical Report #82-19 (July, 1982)

Extreme Points of Bivariate Discrete Distributions with Fixed Marginals

Truc T. Nguyen and Allan R. Sampson

The extreme points of fixed-marginal bivariate discrete probability distributions are characterized, thereby generalizing Birkhoff's Theorem. For the finite case, a constructive algorithm which generates all extreme points, is given. The relationships between the Frechet bounds and other extreme points are discussed. Within the set of extreme points, the upper and lower Frechet bounds are characterized by their respective TP_2 and RR_2 properties.

Technical Report #82-20 (July, 1982)

Counting the Number of pxq Integer Matrices More Concordant Than a Given Matrix

Truc T. Nguyen and Allan R. Sampson

A method for generating and counting the set of matrices of nonnegative integer elements with fixed row and column sums based on the "more concordant" partial ordering is given. A counting formula is presented in the general case. A simple expression is given for $C(r_1,r_2,r_3;r_1,r_2,r_3)$, the cardinality of the set of 3x3 matrices with row sum (r_1,r_2,r_3) and column sum (r_1,r_2,r_3).

Technical Report #82-21 (July, 1982)

The Geometry of Certain Fixed Marginal Probability Distributions

Truc T. Nguyen and Allan R. Sampson

The geometry of the set of pxq p.m.f. matrices with fixed marginals is discussed. The positively quadrant dependent and negatively quadrant dependent subsets are also considered. Explicit graphical representations of these sets are given in the 2x2 and 2x3 cases.

Technical Report #82-23 (August, 1982)

Multivariate Analysis: Some Reminiscences On Its Origin and Development

C. Radhakrishna Rao

The article traces the history of multivariate analysis, the pioneering contributions of R. A. Fisher, the development of multivariate statistical methodology for applications in various fields under the guidance of Fisher, the work of the Indian School of Statisticians under the leadership of P. C. Mahalanobis, the author's experience in the statistical analyses of three large bodies of anthropometric data, and some of the modern trends of research. The origin and development of multivariate analysis clearly show that contact with live problems is essential for worthwhile research in statistical methodology.

Technical Report #82-24 (September, 1982)

Positive Dependence Orderings

George Kimeldorf and Allan R. Sampson

This paper presents a systematic basis for studying orderings of bivariate distributions according to their degree of positive dependence. The general concept of a positive dependence ordering (PDO) is introduced and its properties are discussed. A number of existing orderings are evaluated as to whether or not each is a PDO. A new ordering according to the degree of total positivity of order two (TP_2) is given, and is shown to be a PDO. This TP_2PDO is a subordering of the more positively quadrant dependent PDO.

Technical Report #82-28 (November, 1982)

Robustness Properties of the F-Test and Best Linear Unbiased Estimators in Linear Models

B. K. Sinha and Hilmar Drygas

Consider a linear model $Y = X\beta + \sigma\varepsilon$, $E(\varepsilon) = 0$, $E(\varepsilon\varepsilon') = I_n$ with β,σ unknown. For the problem of testing the linear hypothesis $C\beta = \delta$, $\text{im}(C') \subseteq \text{im}(X')$, Ghosh and Sinha (1980) proved that the properties of the usual F-test being LRT and UMPI (under a suitable group of transformations) remain valid for specific non-normal families. In this paper it is shown that both criterion and inference robustness of the F-test hold under the assumption $\sigma\ q(\varepsilon'\varepsilon)$, q convex and isotonic. This result is similar to a robustness property of Hotelling's T^2-test proved by Kariya (1981). Finally, it is proved that the Best Linear Unbiased Estimator (BLUE) of any estimable function $C\beta$ is more concentrated around $C\beta$ than any other unbiased estimator of $C\beta$ under the assumption that ε is spherically distributed.

Technical Report #82-29 (October, 1982)

On the Kleffe-Approach for Computing Covariance-Operator of Tensor-Products

Hilmar Drygas

Let ε be a vector of expectation zero, with independently, identically quasi-normally distributed components. It is the purpose of this paper to compute the covariance-operator of $\varepsilon^{\hat{\otimes}3}$ and $\varepsilon^{\hat{\otimes}4}$ via a technique developed by J. Kleffe. It turns out that the computations are still tedious, but a decomposition of the combinatorial problems involved is taking place.

Technical Report #82-30 (October, 1982)

Linear Sufficiency and Some Applications in Multilinear Estimation

Hilmar Drygas

In the linear model $Y = X\beta + u$ the question arises when a linear transformation $z = Ly$ contains all information of the linear model. This problem was solved by Baksalary and Kala (Annals 1981), Drygas (Sankhya, forthcoming) and J. Müller (Ph.D. thesis, Kassel 1982). As an application, we consider the estimation of the variance of the observations, its skewness and its kurtosis. This is done by considering so-called derived models. (Anscombe, Pukelsheim, Kleffe.) Linear sufficient statistics are derived for these problems.

Technical Report #82-32 (October, 1982)

Sufficiency and Completeness in the Linear Model

Jochen Muller

This paper provides further contributions to the theory of linear sufficiency and linear completeness. The notion of linear sufficiency was introduced in [2] and [8] with respect to the linear model $E\mathbf{y} = X\beta$, var $\mathbf{y} = V$. In addition to correcting an inadequate proof of [8], the relationship to an earlier definition and to the theory of linear prediction is also demonstrated. Moreover, the notion is extended to the model $E\mathbf{y} = X\beta$, var $\mathbf{y} = \sigma^2 V$. Its connection with sufficiency under normality is investigated. An example illustrates the results.

Technical Report #82-35 (November, 1982)

Diversity and Cluster Analysis of Blood Group Data on Some Human Populations

C. Radhakrishna Rao and Robert Boudreau

The paper discusses some systematic methods for studying differences between individuals within a population through measures of diversity and differences between populations through measures of dissimilarity. The methods are illustrated using data on five blood group systems on some Jewish and non-Jewish populations.

Technical Report #82-36 (November, 1982)

Likelihood Ratio Tests for Relationships Between Two Covariance Matrices

C. Radhakrishna Rao

Likelihood ratio tests for hypotheses on relationships between two population covariance matrices Σ_1 and Σ_2 are derived on the basis of the sample covariance matrices having Wishart distributions. The specific hypotheses considered are (i) $\Sigma_2 = \sigma^2\Sigma_1$, (ii) $\Sigma_2 = \Gamma + \sigma^2\Sigma_1$, (iii) $\Sigma_2 = \Gamma + \Sigma_1$ where Γ may be n.n.d. or arbitrary and the rank of Γ is less than that of Σ_1. Some applications of these tests are given.

Technical Report #82-37 (November, 1982)

Existence of Unbiased Covariance Components Estimators

Jochen Muller

The condition of Pincus (1974) for the estimability of covariance components in normal models is extended to the case of singular covariance matrices.

Technical Report #82-38 (December, 1982)

On Asymptotic Distributions of Test Statistics for Covariance Matrices and Correlation Matrices

C. Fang and P. R. Krishnaiah

In this paper, the authors discuss the asymptotic joint distributions of certain functions of the elements of the sample covariance matrix when the underlying distribution is a mixture of multivariate normal distributions. Application of the above distributions in studying the robustness of certain tests on correlation matrices are also discussed. The authors have also discussed the asymptotic joint distributions of certain functions of the eigenvalues of a multivariate quadratic form. Finally, applications of these results in studying robustness of certain tests on the eigenvalues of the covariance matrix are discussed when the assumption of normality is violated.

Technical Report #82-39 (December, 1982)

Limit Theorems for the Eigenvalues of Product of Two Random Matrices

Y. Q. Yin and P. R. Krishnaiah

In this paper, the authors showed that the spectral distribution of a sequence of the products of random matrices will tend to a distribution function in the limit as the number of variables tend to infinity.

Technical Report #82-40 (December, 1982)

The Limiting Behavior of the Eigenvalues of a Multivariate F Matrix

Y. Q. Yin, Z. D. Bai and P. R. Krishnaiah

Let S_1 and S_2 be random matrices of order pxp which are distributed independently as central Wishart matrices with m and n degrees of freedom respectively. In this paper, the authors showed that the spectral distribution of $nS_1S_2^{-1}/m$ tends to a limit distribution (nonrandom) in probabililty.

Technical Report #83-01 (January, 1983)

Inference on Parameters in a Linear Model: A Review of Recent Results

Jochen Muller, C. Radhakrishna Rao and B. K. Sinha

This paper, in three parts, is a review of recent results on inference on parameters in a linear model. In the first part, the Gauss-Markoff theory is extended to the case when the dispersion matrix of the observable random vector is singular. In the second, robustness of inference procedures for departures in the design matrix, the dispersion matrix and distributional assumptions about the error components is considered. Finally, the third part introduces concepts of linear sufficiency and completeness in linear models, without making any distributional assumptions.

Technical Report #83-03 (March, 1983)

Likelihood Ratio Tests on Covariance Matrices and Mean Vectors of Complex Multivariate Normal Populations and Their Applications in Time Series

P. R. Krishnaiah, J. C. Lee and T. C. Chang

In this paper, the authors reviewed the literature on computational aspects of the distributions of the likelihood ratio statistics for testing various hypotheses on the covariance matrices and mean vectors of complex multivariate normal populations. Applications of some of these test procedures in the area of inference on multiple time series in the frequency domain are also discussed. In the Appendix, the authors give tables which are useful in implementation of various likelihood ratio test statistics discussed in this paper.

Technical Report #83-05 (March, 1983)

Prediction of Future Observations in Polynomial Growth Curve Models: Part 1

C. Radhakrishna Rao

The problem considered is that of simultaneous prediction of future measurements on a given number of individuals using their past measurements. Assuming a polynomial growth curve model, a number of methods are proposed and their relative efficiencies in terms of the compound mean square prediction error (CMSPE) are compared. There is a similarity between the problem of simultaneous estimation of parameters as considered by Stein and that of simultaneous prediction of future observations. It is found that the empirical Bayes predictor (EBP) based on the empirical Bayes estimator (EBE) of the unknown.

Technical Report #83-08 (May, 1983)

Rejection of Multivariate Outliers

B. K. Sinha

An extension of Ferguson's [Fourth Berkeley Symposium on Probability and Mathematical Statistics, 1961, Volume 1] univariate normal results for rejection of outliers is made to the multivariate case with mean slippage. The formulation is more general than that in Schwager and Margolin [Ann. Statist., 1982, Vol. 10, No. 3, 943-954] and the approach is also different. The main result can be viewed as a robustness property of Mardia's locally optimum multivariate normal kurtosis test to detect outliers against nonnormal multivariate distributions.

Technical Report #83-09 (June, 1983)

Multivariate Gamma Distributions and Their Applications in Reliability

P. R. Krishnaiah

In this paper, we review some of the literature on the joint distributions of the failure times of various components in multicomponent systems when the marginal distributions of the failure times are gamma. We also discuss certain multivariate distributions to include the situations when the failure times of certain components are gamma and those of the remaining components are Weibull.

Technical Report #83-10 (May, 1983)

Testing for Positive Quadrant Dependence in Ordinal Contingency Tables

Truc T. Nguyen and Allan R. Sampson

Two new randomization tests are introduced for ordinal contingency tables for testing independence against strictly positive quadrant dependence, i.e., $P(X > x, Y > y) \geq P(X > x)P(Y > y)$ for all x,y with strict inequality for some x and y. For a number of cases, simulation is used to compare the estimated power of these tests versus standard tests based on Kendall's τ, Spearman's ρ, Pearson's ξ^2, and the usual likelihood ratio test. In these cases, subsets of the alternative region are identified where each of the testing statistics is superior. The new tests are found to be more powerful than the standard tests over a broad range of the alternative regions for these cases.

Technical Report #83-11 (June, 1983)

Convexity Properties of Entropy Functions and Analysis of Diversity

C. Radhakrishna Rao

Some natural conditions which a diversity measure (variability) of a probability distribution should satisfy imply that it must have certain convexity properties, considered as a functional on the space of probability distributions. It is shown that some of the well known entropy functions, which are used as diversity measures do not have all the desirable properties and are, therefore, of limited use. A new measure called the quadratic entropy has been introduced, which seems to be well suited for studying diversity.

Methods for apportioning diversity (APDIV) at various levels of a hierarchically classified set of populations are described. The concept of analysis of diversity (ANODIV), as a generalization of ANOVA, applicable to observations of any type, is developed and its use in the analysis of cross classified data is demonstrated. The choice of a suitable measure of diversity for the above purpose is discussed.

Technical Report #83-12 (June, 1983)

Use of Diversity and Distance Measures in the Analysis of Qualitative Data

C. Radhakrishna Rao

The paper discusses some theoretical and practical considerations in the choice of diversity and distance measures for comparing populations in terms of gene frequencies associated with various characteristics. It develops systematic methods for grouping populations by similarity in genetic diversity, apportioning diversity as between and within populations, grouping of populations by similarity in gene frequencies (cluster analysis) and testing consistency of results by using different diversity and distance measures and subsets of data. The methods are illustrated using the data on nine biochemical characteristics of the Makiritare Indians. They can be used in the analysis of any qualitative data, such as those that arise in sociological research.

Technical Report #83-13 (June, 1983)

Inference from Linear Models with Fixed Effects: Recent Results and Some Problems

C. Radhakrishna Rao

A unified theory of BLUE from linear models is provided, where both the design matrix and the dispersion matrix of the error term may be deficient in rank. Problems of simultaneous estimation and prediction from a number of linear models are considered under a compound quadratic loss function. A generalized ridge regression estimator is proposed. Robustness of tests of significance for improper specification of the design and dispersion matrices and departure from normality is examined. The concepts of linear sufficiency and linear minimal sufficiency are introduced and the class of BLUE's is shown to be linear minimal sufficient. Methods for model selection for predicting future observations are suggested. Finally, some properties of empirical Bayes estimators are examined.

Technical Report #83-14 (July, 1983)

Limit Theorems for the Eigenvalues of the Sample Covariance Matrix when the Underlying Distribution is Isotropic

Y. Q. Yin and P. R. Krishnaiah

In this paper, the authors show that the spectral distribution of the sample covariance matrix has a limit when the underlying distribution is isotropic, and the dimension p of this distribution and the sample size n both tend to infinity but $p/n \to y < 1$.

Technical Report #83-15 (July, 1983)

Generalized Inverse of Linear Transformations: A Geometric Approach

C. Radhakrishna Rao and Haruo Yanai

Generalized inverse of a linear transformation A: $\underline{V} \to \underline{W}$, where $\underline{V}$ and $\underline{W}$ are arbitrary finite dimensional vector spaces, is defined using geometrical concepts of projection without considering inner products. The inverse is uniquely defined in terms of specified subspaces $\underline{L}$,$\underline{M}$, and a linear transformation N satisfying some conditions. Such an inverse is called the $\underline{L}$ $\underline{M}$ N-inverse. Moore-Penrose inverse corresponds to the choice N=0. Some optimization problems are considered by choosing $\underline{V}$ and $\underline{W}$ as inner product spaces. Our results extend without any major modification of proofs to bounded linear operators with closed range on Hilbert spaces.

Technical Report #83-16 (July, 1983)

Maximum Likelihood Fitting of STARMAX Models to Incomplete Space-Time Series Data

David S. Stoffer

In this paper, we combine the spatial considerations of the space-time ARMA model and the parametrization of the ARMAX model to formulate a STARMAX model which can be used for modeling and forecasting the dynamics of multivariate populations which are functionally dependent upon spatial characteristics as well as time. Furthermore, due to the physical constraints imposed on a multivariate data collection system in both space and time, this model tolerates very general patterns of missing or incomplete data. As a consequence of Shumway and Stoffer (1982), the EM algorithm proposed by Dempster et al. (1977) is used in conjunction with modified Kalman smoothed estimators to derive a simple recursive procedure for estimating the parameters of the STARMAX model by maximum likelihood.

Technical Report #83-19 (October, 1983)

Concepts of Setwise Dependence

D. Chhetry, G. Kimeldorf and Allan R. Sampson

This paper introduces a number of new concepts of positive and negative dependence among sets of random variables. In particular, setwise association, setwise positive upper (and lower) orthant dependence, and other related setwise concepts are defined. Properties of these various setwise dependence concepts are studied and their relationships are explored. These new concepts are particularly useful in multivariate analysis when not all interrelationships among the random variables are equally important, but rather relationships among certain sets of random variables are of primary importance.

Technical Report #83-20 (October, 1983)

Limit Theorems for the Eigenvalues of Product of Large Dimensional Random Matrices When the Underlying Distribution is Isotropic

Y. Q. Yin and P. R. Krishnaiah

In an earlier paper, (Journal of Multivariate Analysis, Vol. 13, 1983), the authors showed that the spectral distribution of W T has a limit, under certain conditions, when p tends to infinity and W and T are independently distributed random matrices of order p x p; here W is the central Wishart matrix. In this paper, the authors generalized the above result when W is the sample sums of squares and cross products matrix and the underlying distribution is isotropic.

Technical Report #83-21 (October, 1983)

Efficiency of Estimators in the Regression Model with First Order Autoregressive Errors

L. Magee, A. Ullah, and V. K. Srivastava

In this report, the authors consider the problem of estimating the regression coefficients in a linear regression model with first order autocorrelated disturbances when the autocorrelation is unknown. Efficiencies of various estimators of the regression coefficients are investigated.

Technical Report #83-23 (November, 1983)

Convexity of Bivariate Elliptically Contoured Distributions and Applications

S. Iyengar

In this paper we use a recently established partial differential equation for elliptically contoured densities to obtain approximations to probabilities of rectangles and orthants. Applications to the construction of confidence sets are given.

Technical Report #83-24 (November, 1983)

Admissible Linear Estimation in Singular Linear Models

C. R. Rao, B. K. Sinha and Thomas Mathew

The admissibility results of Rao (1976), proved in the context of a nonsingular covariance matrix, are extended to the situation where the covariance matrix is singular. Admissible linear estimators in the Gauss-Markoff model are characterized and admissibility of the Best Linear Unbiased Estimator is investigated.

Technical Report #83-25 (November, 1983)

Tests for Independence of Two Multivariate Regression Equations with Different Design Matrices

T. Kariay, Y. Fujikoshi and P. R. Krishnaiah

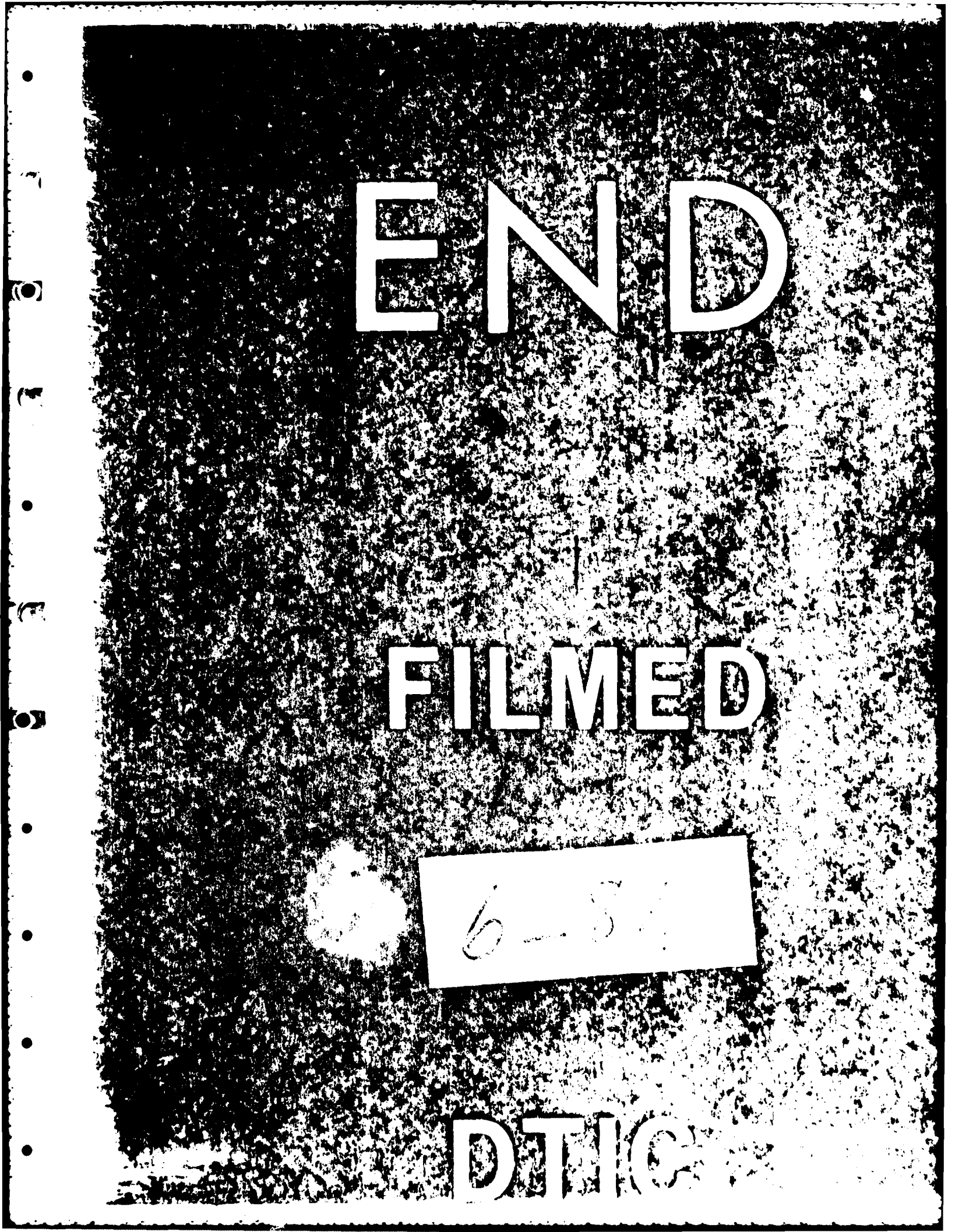
In this report, the authors considered a model with correlated multivariate regression equations (CMRE). Under the above CMRE model, the authors derived a locally best invariant (LBI) test for the independence of two multivariate regression equations. Null and nonnull distributions of the above statistic and two other test statistics are derived. The nonnull distributions are derived under local alternatives.

Technical Report #83-26 (November, 1983)

Standard Errors or Posterior Probabilities and How to Use Them

Willem Schaafsma

Individual-dependent probabilities like those of the patient in clinical decision making, can more or less be regarded as estimates of posterior probabilities. Focusing on a well-defined statistical context, the asymptotic distribution of the vector of underlying estimators is obtained. These results form the basis of the decision support system POSCON, which provides estimates of posterior probabilities together with corresponding standard errors and correlations. The results can also be used in deriving approximations for the additional error rate of certain classification procedures.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